Lockheed Martin Space Mission Systems & Services
Science, Engineering, Analysis, and Test
2400 NASA Road 1, P.O. Box 58561, Houston, TX 77258-8561
Telephone (281) 333-5411

LOCKHEED MARTIN

June 24, 1999
Subtask Order: HELEC3B1
Contract: NAS9-19100
HDID-2G42-1130

TO:	A.F. Behrend	/NASA/EC	
	D.L. Henninger	/NASA/EC	
	D.C. Thompson	/NASA/EC3	
	T.O. Tri	/NASA/EC3	
	C.H. Lin	/NASA/EC2	
	M.K. Ewert	/NASA/EC2	
	A.J. Hanford	/LM/C70	
VIA:	A.H. Milliken	/LM/C70	*Original Initialed by AHM*
	J.F. Keener	/LM/C70	*Original Initialed by JFK*
	F.F. Jeng	/LM/C70	*Original Initialed by FFJ*
FROM:	B.E. Duffield	/LM/C70	

SUBJECT: **Advanced Life Support (ALS) Technologies List**

SUMMARY: This list of potential ALS technologies is intended to be as comprehensive as possible so that it can be used to guide trade off studies that search for the best possible combination(s) of technologies for future missions. Here 'ALS technologies' is very broad, meaning any technology that has a significant interaction with the traditional life support functions of providing fresh air and water. Please report any additions or correction to the author (281) 333-7384 or e-mail at bruce.duffield@lmco.com.

DISCUSSION:

Air Revitalization System (ARS)

CO_2 Removal

- LiOH - Lithium hydroxide for CO2 removal without regeneration, high resupply rate.

$$2LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O$$

- Molecular Sieve (4BMS or 2BMS) - In the 4BMS 2 synthetic zeolites beds are used alternately for absorption and desorption of CO_2 from the atmosphere in conjunction with 2 moisture removal beds. The 2BMS uses a functional carbon molecular sieve and moisture removal beds are not needed.
- Solid Amine Water Desorption (SAWD) - A steam heated solid amine (WA-21) is used instead of the carbon molecular sieve in the 2BMS. Solid amine degrades with time requiring bed changeouts & moisture is released adding load to the Condensing Heat Exchanger. The SAWD uses steam for desorption where the 4BMS & 2BMS use heat and vacuum for desorption.
- Solid Amine Vacuum Desorption (SAVD) - Like the SAWD except uses vacuum to pull CO_2 and H_2O from the solid amine beds.

- Electrochemical Depolarization Concentrator (EDC) - Concentrates CO_2 using H_2 & O_2 in electrochemical cells. Requires O_2 generation H_2 gas (fire or explosion risk). EDC is a net power generator.

$$CO_2 + \tfrac{1}{2}O_2 + H_2 \longrightarrow CO_2 + H_2O + Elec.energy + Q_{heat}$$

- Air Polarized Concentrator (APC) - Like the EDC but doesn't require H_2, *i.e.* safer but is a net power consumer.
- O_2 Concentrator
- Electroactive carriers within membranes - Fixed within membranes capable of binding CO_2 in the reduced state and releasing CO_2 in the oxidized state. Low TRL.
- Membrane Removal - To date has shown inadequate selectivity for CO_2.
- Green Plants - Photosynthetic conversion of CO_2 to O_2
    1. Soil & water
    2. hydroponics
    3. zeoponics
    4. aeroponics

$$6CO_2 + 6H_2O + light \longrightarrow C_6H_{12}O_6 + 6O_2$$

- Algal Systems - Photosynthetic conversion of CO_2 to O_2.
- Enzyme facilitated CO_2 capture - Seen at the ALS poster session at the Center for Advanced Space Studies March 1999, work of Dr. Michael Tractenberg, (see Sandra Brasseaux for details).

CO_2 Reduction

- Sabatier - produces water and methane. Uses high temp. (450 - 800 K)

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O + heat$$

- Bosch - produces Carbon and water. Uses high temp. (700 - 1000 K)

$$CO_2 + H_2 \longrightarrow C + 2H_2O + heat$$

- ACRS - a Sabatier, g/l separator and Carbon Formation Reactor (CFR) for CH_4 Pyrolysis, CFR packs carbon better than Bosch but uses operating temp of 1100 K. *Sabatier Rx with methane conversion to carbon.*

$$CH_4 \longrightarrow C + 2H_2$$

- CO_2 Electrolysis - Reduces CO_2 & produces O_2, operates at high temp (1100 K) and low TRL.

$$CO_2 + H_2O \longrightarrow CO + H_2O + \tfrac{1}{2}O_2$$

$$CO \longrightarrow C + CO_2$$

- Green Plants - Photosynthetic conversion of CO_2 to O_2.
    1. Soil & water
    2. hydroponics
    3. zeoponics
    4. aeroponics

$$6CO_2 + 6H_2O + light \longrightarrow C_6H_{12}O_6 + 6O_2$$

- Algal Systems - Photosynthetic conversion of CO_2 to O_2.

O_2 Generation

- Solid Polymer Water Electrolysis (SPWE) - Uses solid polymer electrolyte to produce O_2 from water.

Electrolysis Rx.

$$2H_2O + Energy \longrightarrow 2H_2 + O_2 + heat$$

- Static Feed Water Electrolysis (SFWE) - Uses aqueous electrolyte to produce O_2 from water.
- CO_2 Electrolysis - Reduces CO_2 & produces O_2 but operates at high temp (1100 K) and low TRL.
- Green Plants - Photosynthetic conversion of CO_2 to O_2
    1. Soil & water
    2. hydroponics
    3. zeoponics
    4. aeroponics
- Algal Systems - Photosynthetic conversion of CO_2 to O_2
- Artificial Gill - Binds O_2 from low concentration streams by combining O_2 with organometallic compounds like hemoglobin. Could be used to recover O_2 from plant chambers or the Martian atmosphere.

Nitrogen Supply

- Gas storage - high pressure liquid N_2
- Thermal Catalytic Dissociation of hydrazine

$$3N_2H_4 \longrightarrow N_2 + 4NH_3 + heat$$

$$4NH_3 + heat \longrightarrow 2N_2 + 6H_2$$

Trace Contaminant Control System (TCCS)

- Activated Charcoal Adsorption
- Photo catalyst oxidation
- ISS Baseline TCCS
- Improved TCCS (see John Graf) - features a regenerable sorbent bed that is regenerated using space vacuum
- Regenerable Air Purification System (RAPS) - (NASA (ARC) & Vanderbilt U. joint effort) use of a humidity-swing desorption cycle, which uses less power than a thermal desorption cycle and requires no venting of air and water to space vacuum.
- Biological Air Filter - Contains a liquid phase, containing microbes, separated from the gas phase (air) by membranes.
- Soil Reactor Beds (SRB) - Air movement through living soil that supports a population of plants.

Other

- Magnetic Gas Liquid Separator - Boeing Corp. technology in testing stage. Seen at the ALS poster session at the Center for Advanced Space Studies March 1999.

Water Recovery System (WRS)

ISS Baseline Architecture

- Vapor Compression Distillation (VCD) - 96% recovery of water from urine with low energy use. Rotating parts. Can have problems with recondensing of volatile organics and ammonia.
- Multifiltration (MF) – Purification through filters and packed columns; high expendables.
- Volatile Removal Assembly (VRA) - removes low molecular weight organics using catalytic oxidation.

Alternate ISS Baseline Architecture

- Thermoelectric Integrated Membrane Evaporation System (TIMES) - Uses hollow fiber membrane technology. 95% water recovery. Can have problems with recondensing of volatile organics and ammonia.
- Multifiltration (MF) - Purification through filters and packed columns; high expendables.
- Improved Post Processor - pre-oxidizer plus adsorbent beds.

Advanced Node 3 Architecture

- Bioreactor - TOC and Nitrogen oxidation using cultures of mixed microbes.
    1. Packed Bed Biological Water Processor (PBWP) - anerobic packed bed reactor
    2. Nitrification Biological Water Processor (NBWP) - aerobic membrane reactor - O_2 delivery via membrane for nitrification
    3. Membrane Biological Water Processor (MBWP) - aerobic membrane reactor - O_2 delivery via membrane for TOC reduction.
    4. Biological Water Processor (BWP) - aerobic reactor withO_2 delivery not via membrane.
    5. Microfiltration or Ultrafiltration – Cross flow membrane processes defined by membrane pore size.
- Reverse Osmosis (RO) - Low energy use and low expendables; produces brine requiring additional treatment.
- Air Evaporation System (AES) - Used in Advanced Node 3 Architecture as an RO brine processor but could also be used as a urine processor. Uses evaporation via a heated wick and condensation.
- Post Processor - TOC and organic salts polishing by adsorption and ion exchange.

Alternative Water Purification Technologies

- Vapor Phase Catalytic Ammonia Removal (VPCAR) – Vacuum vaporization & high temperature catalytic oxidation of volatile impurities *i.e.* doesn't need post processing treatment. Uses a wipe film rotating disc and high operating temperatures.

- Super Critical Wet Oxidation (SCWO) - Waste treatment above 647 K and 2.21 x 10^7 Pa. Complete oxidation of organics and precipitation of most inorganics.
- Aqueous Phase Catalytic Oxidation Post-treatment System (APCOS) - Polishing apparatus that uses catalytic oxidation.
- Electrodialysis - Uses ion exchange resins and membranes to deionize water.
- Water Recovery from Condensate - Recovered from transpiration of plants (includes gray water recovery from plants) or evaporated from breathing, skin surfaces or other sources.
- Many other kinds of bioreactor e.g. destruction of organics such as soap in the Nutrient Delivery System (NDS) of a hydroponics system by the microbes in the root mat, continuously stirred tank reactors, etc. A Composter might be able to treat heavily contaminated water e.g. urine better than other types.
- Photocatalysis - consumable free post-processing
- Freeze purification by lyopholization (*i.e.* freeze drying) - lower latent heat than distillation processes.
- Other types of still, e.g. using solar energy directly or thermopervaporation. (The latter may be related to TIMES.)
- Other electrochemical approaches involving ozone or hydroxyl ions generated in situ to destroy organics.

Waste Management Solids Processing System (SPS)

- Store waste
- Physical Chemical (P/C) fullup
    1. Super Critical Wet Oxidation (SCWO) - No catalyst needed. Can reuse most of the heat generated. Produces potable water from all input wastewaters. Operates 647 K & 2.21 x 10^7 Pa.
    2. Wet Oxidation - High temp & pressure oxidation of wet slurries. Output depends on the temperature and pressure used. Particularly attractive in conjunction with plants as CO_2 is produced.
    3. Combustion/Incineration - Requires evaporation prior to combustion. Highly oxidized waste products.
    4. Electrochemical Oxidation - Non- thermal (oxidizes with catalytic electrodes) and doesn't use atmospheric O_2. Less power requirements than SCWO, Wet Oxidation or Combustion/Incineration.
    5. IRAD (Hamilton Standard) -
- ½ Biological Digestion/Composting
    - i. composting
    - ii. Continuous Stirred Tank Reactor (CSTR) - could be used to recover nutrients for plants.
- ½ P/C
    - iii. Carbonization - heat to 250 °C & 10342 kPa (1500 psi) then cool
        6. recover water.
        7. for deactivation after biological processes
- Sterilize & Stabilize - This is the only method that does not require O_2 and would be most appropriate for partly open food systems.
- Pyrolysis
- Freeze Dry
- Dehydrate

Thermal Control System (TCS)

Heat Acquisition

- Aluminum Coldplates
- Condensing HX's
- Avionics air HX's
- Adsorbent/desiccant H2O removal
- Cold plate shelf - integrate with structures, metal or composite, possible incorporation of heat pipes
- Carbon velvet heat exchanger
- Fault tolerant heat exchangers
- Thermal storage
- Light weight cold plates & heat exchangers.

Heat Transport

- Single-phase pumped loop
- Low-power two-phase pumped loop
- Solar vapor compression heat pump
- Internal heat pump - for low temperature loads
- Thermal-powered heat pump
- Fluids that can be used inside and outside the spacecraft (single phase)

Heat Rejection

- Aluminum radiators
- Flexible fabric radiators - metal or carbon
- Laminate radiators
- Composite radiators
- Mars convection device
- Parabolic radiator shade
- Radiator surface cleaning and refreshing
- Water membrane evaporator (WME)
- Low cost Sublimator

Biomass Production System (BPS)

1. Lighting
    a. Light Emitting Diodes (LED)
    b. Microwaves - potential power saver, could increase efficiency from 35% to 50%.
    c. Improved Reflectors.
    d. Water Jacketed Lamps.

- Microbiological Process Control - control by DNA probes or carbon probes.
- Chemical Assay System - could reduce redundancy of assay equipment and therefore system mass
- Crop Production Selection Technologies - specific technologies for growing specific crops particularly specialized crops like soybeans, peanut, sweet potato and white potato.
- O_2 Concentrator
- Tray lid conveyor
- Tray lift

- Processing conveyor
- Tray lid
    2. Support Frame
    3. Rooting Matrix
- Automated Seeder
- Harvester
- Higher productivity crops.
- Shorter crops.

Food Processing System (FPS)

- Extruder - uses shear force, increased temperature and increased pressure to convert plant material into edible food ingredients. Increases available food texture and variety.
- Grain/Flour Mill - convert various food crops to flour.
- Soy Milk Machine - Needed for processing soybeans to milk, tofu (used as meat substitute) etc.
- food processor
- bread machine
- dishwasher
- refrigerator
- freezer - active
- freezer - passive
- dehydrator
- press (oil extraction hydraulic)
- automatic tofu/milk (ProSoya)

Human Accommodations System (HAS)

- Washer/dryer
- Disposable vs. permanent clothing
- dishwasher
- galley
- shower
- trash compactor

Please call the author at (281) 333-7384 or e-mail at bruce.duffield@lmco.com with any questions.

Bruce E. Duffield
Fluid Process Analysis Projects

References

1. Eckart Peter, Spaceflight Life Support and Biospherics, Herbert Utz Publisher, Munich Germany ‘94.
2. Personal Communications: Chin Lin, Mike Ewert, Fred Smith, Sandra Brasseaux, - NASA JSC, John Fisher NASA ARC, John Sager NASA KSC, Alan Drysdale -Boeing KSC, Frank Jeng, Jannivine Yeh, Kevin Lange, Tony Hanford - Lockheed/Martin Houston.

3. Barta Daniel, Castillo Juan M, Fortson Russ E, The Biomass Production System for the Bioregenerative Planetary Life Support Systems Test Complex: Preliminary Designs and Considerations, SAE Technical Paper Series 1999-01-2188.

DISTRIBUTION:

A.F. Behrend	/NASA/EC
D.L. Henninger	/NASA/EC
D.C. Thompson	/NASA/EC3
T.O. Tri	/NASA/EC3
C.H. Lin	/NASA/EC2
M.K. Ewert	/NASA/EC2
A.J. Hanford	/LM/C70
A.H. Milliken	/LM/C70
J.F. Keener	/LM/C70
F.F. Jeng	/LM/C70
B.E. Duffield	/LM/C70
Task Order File	